4

The Mechanism of respiration from the orthodiagraphic standpoint.

Dr. J. F. HALLS DALLY, London.

With your permission I propose to outline briefly some of the results which I have attained by the use of the Orthodiagraph in the study of that intricate subject, the Mechanism of Respiration, in the hope that they may be not without interest to the present Congress.

In studying changes which occur in the shape, size, and position of the internal organs as a result of their functional activity, previous observers have worked at a disadvantage in that practically all the methods used by them in their researches have involved more or less disturbance of the normal arrangement of parts and therefore of function. During the past ten years movements of the thoracic contents have been studied by means of the observation of their moving shadows on the fluorescent screen. But these X-ray methods, although affording useful indications, have done no more than approximate to exact measurement of the movements of the internal organs owing to the distortion caused by shadow-magnification. If, however, one can not only see what is going on inside the trunk, but can also accurately measure the vital movements great light is immediately thrown upon the phenomena of respiration and circulation.

In the Orthodiagraph I have found a machine which fulfils these conditions. The form of instrument I have used is the one invented by Dr. Groedel of Bad Nauheim.

By means of this instrument it is possible, with almost mathematical accuracy, te measure motionless objects which lie in a plane parallel with the vertical transverse plane of the body, and to measure moving objects with greater approximation to exactitude than can be attained in any other manner.

The explanation is as follows:

In a fluorescent tube, when the electrons shot off from the kathode suddenly are intercepted by the antikathode, they set up electric vibrations in the ether precisely similar to those of light, save that their wavelengths are much shorter. By cutting

off all the rays projected from the antikathode, with the exception of the central pencil, and by conducting this latter round the shadow-margin of an organ, irrespectively of the greater or less magnification of the shadow on the screen, a record can be traced which represents the actual size of the object examined:

In order to find out how closely one can measure, a series of experiments was undertaken, two of which are here recorded.

Experiment I. A brass quadrant was placed between the leaves of a book 10 centimetres distant from the surface of the book nearest to the fluorescent tube, so as to imitate the density of the tissues of the body. Orthodiagraphic measurement was then made, and the resultant tracing was found to correspond closely with the original.

Experiment II. A similar experiment was performed with a metal ring, the resulting circle of dots corresponding with great exactitude to the outline of the original.

I propose to consider the subject under the following heads[1]):

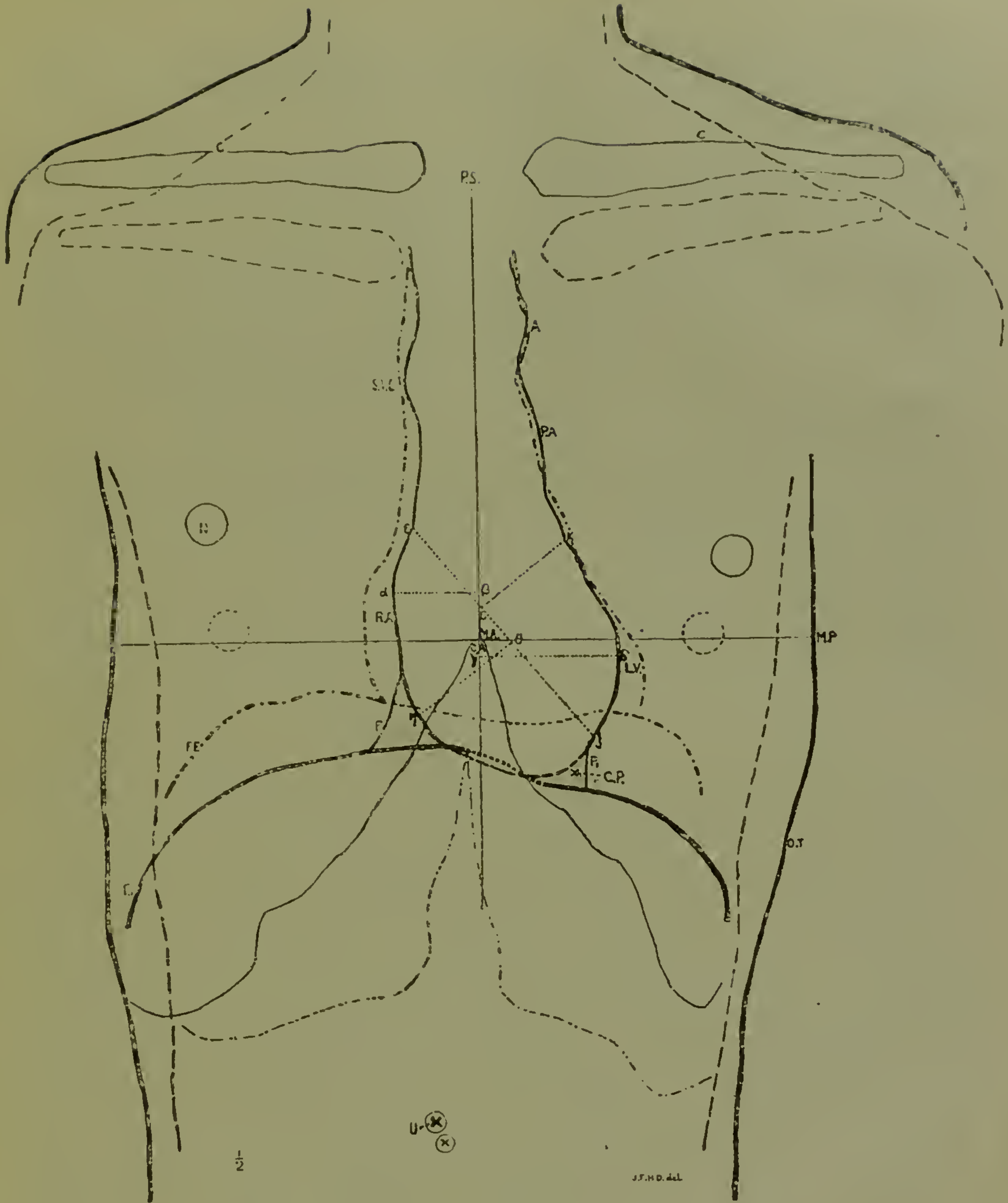
I. Results obtained by Orthodiagraphic Measurement of Changes in the Trunk which occur during Respiration.
II. The Movement of the Vertebral Column in Respiration.
III. The Level of the Diaphragm.
IV. The Range of Movement of the Diaphragm.
   1. After death.
   2. During life $\begin{cases}\text{at rest.}\\ \text{in action.}\end{cases}$

I. Results obtained by Orthodiagraphic Measurement of Changes in the Trunk which occur during Deepest Possible Respiration.

The average changes which occur during inspiration in a series of one hundred healthy subjets, of ages varying between 15 and 35, are recorded as follow:

(1) The neck is shortened 10 mm., and widened on the right side 9 mm., on the left side 7 mm.

[1]) A summary of the chief results of this investigation is embodied in a paper read before the Royal Society, Feb. 6, 1908, and published in the *Proceedings of the Royal Society*, B, vol. lxxx., 1908.



Orthodiagram No. I. Subject in antero-posterior position.

C.	Mid-clavicular point.
P.S.	Presternal notch.
S.V.C.	Superior vena cava.
R.A.	Right auricle.
A.	Aortic arch and first portion of descending aorta.
P.A.	Left pulmonary artery.
L.V.	Left ventricle.
P.	Pericardium and plicae adiposae.
P_1.	Pericardium.
$\alpha\beta$	Diameter of right auricle.
$\gamma\delta$	Diameter of left ventricle.
εE	Longitudinal diameter of heart.

$\eta\delta + \iota\kappa$	Diameter of right ventricle.
N.	Nipple.
U.	Umbilicus.
F.E.	Forced expiration. } Position of diaphragm in.
N.E.	Normal expiration. } Position of diaphragm in.
N.I.	Normal inspiration. } Position of diaphragm in.
F.I.	Forced inspiration. } Position of diaphragm in.
M.A.	Meso-metasternal articulation.
M.P.	Meso-metasternal plane.
O.T.	Outline of trunk.
C.A.	Infracostal angle.
C.P.	Cardio-phrenic space.

(2) The shoulders are raised on te right side to a slightly greater extent than on the left, the average on the right being 16 mm., that on the left 14 mm.

(3) The presternum moves 30 mm. in an upward, and 14 mm. in a forward diameter.

(4) The clavicles execute a combined upward, forward, and outward movement, the vertical range of their inner ends on the right side being 28 mm., on the left side 27 mm.; of their outer ends, on the right side 21 mm., on the left side 16 mm. The divergence from the median line is, on the right side 7 mm., on the left side 6 mm.

(5) The meso-metasternal articulation either may remain in the same horizontal plane, or may rise as much as 46 mm. The average ascent is 28 mm.

(6) Widening of the infracostal angle occurs, the interval between the costal margins, measured on each side at a level of 30 mm. below the mesometasternal articulation, being increased by 26 mm.

(7) The trunk is widened at the level of the meso-metasternal plane 9 mm. on the right side and 8 mm. on the left and midway between the meso-metasternal plane and lowest point of the costal margin, 9 mm. on the right side and 11 mm. on the left.

(8) The umbilicus is retracted and drawn upwards in deep respiration for a distance of 13 mm., on account of the active recession of the abdominal wall produced by the contraction of the abdominal muscles, which, in this phase of respiration, act as antagonists of the spinal muscles. The upward displacement of the umbilicus is usually to the right, but may be median or to the left, the lateral deviation being 7 mm.

(9) The heart and pericardium together undergo important changes in size and position as a result of the respiratory movements, being considerably lengthened and narrowed in inspiration, and shortened and widened during expiration.

(10) The pericardium at the level of its attachment to the central tendon of the diaphragm, in the adult measures 80 mm. in antero-posterior diameter.

Orthodiagram No. I, of the chest of a healthy male aged 20, forms a typical example of most of the above-mentioned movements.

II. The Movement of the Vertebral Column in Respiration.

The movement executed by the spinal column in respiration is an important one, and has been ignored. I can find no reference thereto in any of the eight latest and best-known textbooks of physiology published in Great Britain. That this movement is actual and of mechanical advantage in breathing can be verified by visual and orthodiagraphic examination.

1. *Visual Examination.*

a. In the upright lateral position the respiratory spinal movement becomes most evident if a succession of deep respirations be taken. On inspiration the shoulders are squared and the head elevated and drawn backwards, then there is a gradual backward movement of the whole thoracic spine, with simultaneous extension of the upper thor. vertebrae as far as the supr. scapr., in consequence of which in deep breathing the upper thoracic region is widened antero-posteriorly. When respiration becomes profound and the upper half of the spine is relatively much displaced backwards, the shifting of the centre of gravity is compensated for by a forward movement at the hip-joint, which has the effect of throwing forward the sacrum and lower lumbar spine. Less intense respiration produces correspondingly less effect, and in quiet breathing no forward movement at the hip-joint is necessary. The throwing backwards and fixation of the head and shoulders together with the forward tilting of the pelvis affords the greatest opportunity for unimpeded and deep breathing, and this position instinctively is assumed by those whose pursuits necessitate maximum aeration of the lungs. This attitude is also most effective for voice-production, since not onlydoes maximum expansion of the upper part of the thorax allow of large intake and storage of air, but the thorax in its capacity as resonator is brought as near as possible to the vocal cords.

b. In the upright posterior position the spinous processes appear to move beneath the skin downwards on inspiration and upwards on expiration, this being very noticeable in thin people when they respire deeply. A small proportion of this inspiratory downward movement is a true one due to the extension of the vertebral columm, but the rest of it is caused by the skin being drawn upwards over the spinous processes owing to raising of the shoulders.

2. *Orthodiagraphic Examination.* The shadow of the vertebral column is seen clearly separated off from that of the pericardium and great vessels by a transradiant triangle the base of which is formed by the upper surface of the diaphragm. On inspiration the posterior wall of this triangle, which is formed by the spinal column, is seen to recede, to a greater extent below than above, and so to open out the interval from before backwards. With subsequent expiration the spine advances.

Explanation of the spinal respiratory movement. A general rectification of the curvature of the thoracic portion of the vertebral column takes place. In a series of eight orthodiagraphic observations upon healthy adults of both sexes in the lateral oblique position, I found that the average antero-posterior range of spinal movement was:

At upper opening of thorax, oppisite 1st thoracic vertebra, 6 mm. Midway between upper opening of thorax and level of diaphragm in deep inspiration, opposite 5th thoracic vertebra, 7.5 mm.

At level of posterior part of diaphragm, in deep inspiration, opposite tenth thoracic vertebra, 9 mm.

These measurements show that on the average the spinal column is most displaced towards the lower part of the thoracic curvature, and that rectification lessens from below upwards. Individual differences, however, are not infrequent. The straightening out of the thoracic curve, which occurs especially in that segment of the spine which articulates with the sixth, seventh, eighth, and ninth ribs, is due to contraction of the erector spinæ muscle which produces backward extension of the vertebral column, whilst at the same time the sternum is raised upwards and forwards by contraction of the cervical and thoracic elevator muscles, thus bringing a larger costal arc into the place previously occupied by a smaller one, and so increasing the antero-posterior diameter of the thorax. Upon the ribs assuming a position of less obliquity, the spinal column, being far more limited in its possible range of movement than the sternum, on account of its multiple attachments, can only execute a fraction of the sternal movement. Towards the end of inspiration, as the movement of the sternum reaches its dynamic limit, the remainder of the force of the respiratory cycle is spent upon the spine, which accordingly, during the latter half of inspiration, shows progressive mobility.

In inspiration the spinous processes are approximated and closely overlap, thus forming a natural protection against hyper-extension of the vertebral column and consequent injury to the cord. The bodies of the vertebræ show slight divergence anteriorly in consequence of the opening out of the intervertebral discs, and the anterior common ligament is made taut. Correspondingly, the ribs are separated, and so the chest is enlarged in forward, outward, and upward diameters. In expiration the reverse takes place; the spinous processes separate, the bodies are approximated anteriorly, and the ribs are brought much nearer to each other.

Measurement of the Spinal Movement. The spinal movement is best estimated by means of the orthodiagraph. The subject is turned into the right or left lateral oblique position until the maximum area of transradiance and the greatest amount of luminosity are obtained between the shadow of the vertebral column behind and of the aorta in front. This involves a rotation through an angle of from 30 to 45 degrees. The shadow of the vertebral column forming the posterior boundary of the interval is then seen to move backwards and forwards rhythmically with respiration, the apparent movement being from 6 to 9 mm. Owing to the obliquity with which the normal incident pencil of rays strikes the anterior surface of the spine, the real movement in this instance is larger than the indicated movement. The exact amount of movement which the spine has undergone readily can be calculated.

III. The Level of the Diaphragm.

1. *After Death.* — In order to ascertain the "level" of the diaphragm in man, in the first place it is necessary clearly to understand what this term implies. After death the position of the diaphragm, then simplest to verify on account of its immobility and ease of access, indicates only one phase of respiration; during life, on the other hand, the level rises or falls with each stage of the respiratory cycle. The resting period occurs at the end of moderate expiration, and the position which the diaphragm consequently assumes is conveniently taken as its level during life. Deep expiration is the terminal act of life: so that when the

contraction effect of rigor mortis has passed away, the diaphragm is found in a position of complete expiration, being in other words, thrust up by positive intra-abdominal pressure and drawn up by negative intra-thoracic suction. Manometric observations easily prove that, after death, these pressures exist, and the speedy return of the lungs to the *status quo ante* after artificial distention within reasonable limits, shows that death does not limit elasticity, at all events for some hours. Hence we see that the level of the diaphragm post-mortem is not quite the same as the level intra-vitam, but a little lower.

From the results of an examination of eighty dissecting-room and post-mortem-room cases, I find that the average highest point of the dome of the diaphragm in the cadaveric position is situate, on the right side, at the level of the upper border of the fifth rib in the mid-clavicular line; on the left side, in the mid-clavicular line at the lower border of the fifth rib. This corresponds with the results of orthodiagraphic measurement in bodies of healthy persons who have met with sudden death.

2. *During Life.* — Arguments from the pathological to the physiological being often fallacious, deductions as to the level of the diaphragm, based merely on statistics from the post-mortem and dissecting-rooms, when applied directly to the healthy living subject, are liable to mislead. The average level of the diaphragm, calculated for healthy living people, probably should be higher than the level given above, since in the majority of dissecting-room bodies, owing to atrophy of muscle fibre and laxity of ligamentous attachment accompanying advancing years, the diaphragm stands at a lower level than it ought. Although some diseases raise the diaphragm, most diseases lower it; hence it is most likely that, for pathological states also, the balance is struck too low.

Whilst it is true that, by inspection and percussion, we can map out a line on the surface of the thorax which corresponds approximately to the margin of the diaphragm, no further information is at our disposal relative to the contour of the domes and the level of these and of the central tendon. Orthodiagraphy here is of great service, in that it renders visible and measurable the rise and fall of the diaphragm, and the exact level which it attains in different phases of the respiratory cycle.

(*a*) *At Rest.* — The dome of the diaphragm rises a little higher

on the right side than on the left. In the fœtus the dome usually is on a level with the fourth rib or interspace; in young infants its level is anywhere between the fourth and seventh ribs; in children it stands about opposite the fifth rib. In moderate expiration in a healthy adult the average position assumed by the highest point of the dome on the right side is opposite the level of the fourth intercostal space, or, less frequently, a little internal to the junction of the fourth rib with its cartilage, this being also the surface-marking for the right lobe of the liver; on the left side the average highest point is on a level with the upper border of the fifth rib at its costo-cartilaginous junction, which point also marks the position of the fundus of the stomach, or, if the stomach is contracted, the upper limit of the transverse colon. If the level is taken in terms of spinous processes, the right dome is found most often between the seventh and eighth, the left summit between the eighth and ninth, whilst the central tendon lies a little above the tip of the eighth. Posteriorly the lower edge of the diaphragm is situated on each side at the level of the twelfth thoracic spine. Anteriorly the level of the central tendon corresponds with the meso-metasternal articulation or is slightly above it, according as to whether the diaphragm is highly arched or not, whilst posteriorly it is opposite the body of the eighth thoracic vertebra.

The level of the diaphragm in its passive state, and to some extent in its active state, is influenced by the state of fulness or emptiness of the intra-abdominal viscera, and is raised or lowered accordingly. Gastric distension can produce a considerable rise in level on the left side. Lessening of the content of blood in the thorax also is said to cause elevation of the diaphragm.

(*b*) *In Action.*—Notwithstanding that the level of the diaphragm during life conveniently may be taken as that which is assumed during the resting period, yet for more detailed research into the causes which limit diaphragmatic action, it is necessary to record the exact height of the domes and central tendon in the four phases of moderate and deep inspiration and moderate and deep expiration. Although, to some extent, these levels can be inferred from inspection, palpation, and percussion, of which the latter is most helpful, and the position of the diaphragm deduced from a delimitation of the lower limits of lungs and heart and upper

border of liver, spleen, and stomach, yet the inference lacks the scientific exactitude which is essential for the determination of slight variations from the normal, mainly because little more than the margin of the diaphragm can be mapped out by these methods, whilst the position of the domes is a matter of conjecture. Orthodiagraphic measurements, however, supply the precise information required concerning each portion of the moving or resting diaphragm, and as a result of examination of the subject in various positions, one is enabled to obtain a composite clinical picture.

In attempting to ascertain the level in action, it is advisable to take some landmark as a point from which to measure, the position of which as nearly as possible corresponds with the mean average cadaveric position. The variability in position of the costal arches render these unsuitable as a basis for visceral surface-markings. Indeed, in individuals of the same sex and age, the width of the ribs and cartilages and of the intercostal spaces may differ considerably, and, moreover, may be relatively unequal on the two sides. The nipple-level is still more unreliable. Although the meso-metasternal sutural line, *i.e.* the junction between gladiolus and ensiform cartilage, presents slight changes in level according to age and sex, yet it meets the above-mentioned conditions, and forms a much more constant point from which to measure, since, in the European adult, the combined pre-mesosternum is not liable to much individual variation in length. Hence I have adopted the meso-metasternal articulation as the basis from which to measure, and the line drawn horizontally through this point—these meso-metasternal plane—as the plane to which the level of the rise and fall of the diaphragm of each side may be referred, and all orthodigraphic measurements of the position of the domes and central tendon have been taken in millimetres above and below the level of this plane in preference to other and more usual landmarks.

IV. The Absolute Range of Movement of the Diaphragm.

The absolute range of movement of the diaphragm between deep inspiration and deep expiration in the adult male is, on the right side 34 mm., on the left side 32 mm. The range in adult females amounts to 27 mm. on the right side and 25 mm.

on the left side, making the total average range 30 mm. on the right side and 28 mm. on the left. Up to now the excursion of the diaphragm has been stated at about double the above figures, this being due to the fact that, until the introduction of the orthodiagraph, by which the exact range of movement is recorded, it has been impossible accurately to allow for X-ray shadow-magnification. In quiet respiration the experimental error in the estimation of the range of movement has been much less, owing to the movement being but slight. In adult males the diaphragm in quiet respiration moves 16 mm. on the right side and 14 mm. on the left side; in adult females 9 mm. on the right side and 10 mm., on the left; whilst the total average movement is 12·5 mm. on the right side and 12 mm. on the left. From these figures we see that movement in quiet respiration is approximately equal on the two sides, whilst in deep breathing the excursion is, for most people, slightly greater on the right side than on the left. In diagnosis the movement in deep respiration is the important one to observe.

Table, showing in millimetres the absolute descent of the central tendon in a series of ten cases orthodiagraphically examined in the right anterior oblique position.

Sex.	Age.	Descent at posterior border of pericardium.	Descent midway between anterior and posterior borders of pericardium.	Descent at anterior border of pericardium.
		mm.	mm.	mm.
M.	25	26	30	25
M.	14	4	15	7
M.	8	11	7	6
M.	19	35	36	28
F.	19	11	16	12
F.	22	12	18	15
F.	20	32	42	35
F.	22	12	7	6
F.	13	16	15	14
F.	17	31	25	22
Total average descent.		19 mm.	21.0 mm.	17 mm.

More extended observations confirm the above results, and show that the average descent of the central tendon of the diaphragm is 19 mm., its movement being greatest midway between anterior and posterior borders of pericardium, intermediate at the posterior border, and least at the anterior border of the pericardium.

Before I close I should like to allude to the excellent orthodiagraphic work which has been done from the clinical aspect by Professor WENCKEBACH of Groningen, and to say on behalf of many workers in England how much we owe clinically to the flood of light which has been thrown on enteroptosis and other circulatory and nervous maladies.

Just a word concerning Teleradiography. I am hoping that this latest method will still further increase our knowledge of intrathoracic and intra-abdominal physiological and pathological conditions.

If comparative measurements are to be undertaken it will be necessary so to standardize the teleradiograms that one can make certain that no change in position of patient, or any other error has been introduced between the times of the two exposures. The method is at present too new for me to speak with any confidence as to its capabilities, but I trust to learn something of its value from those present who have had experience of its working.